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The Galvanic Battery in its various Practical Applications as an Igniting Agent.—By Lieut. R. BAIRD SMITH, Bengal Engineers.

INTRODUCTORY REMARKS.

The dependence of the action of the Galvanic Battery on chemical principles, the excitation of that action by the employment of chemical agents, and the habit of considering the Battery as an instrument of scientific research rather than of practical utility, have tended, to a certain extent, to excite impressions unfavourable to its extensive applicability in engineering operations. Practical men naturally dread employing any agent of whose nature they are not thoroughly cognizant, and are therefore liable to be prejudiced against the Battery, by finding themselves unable to apprehend the rationale of its effects. To aid in the removal of such an impression, it may be remarked that an acquaintance with the theory of the Battery, is by no means essential to the comprehension of its mechanical details and applications, as a little experience would immediately prove. A few opportunities of observing the Battery in action, of noting the different manipulations, such as forming connections, apportioning solutions, &c. will, with common intelligence, enable any one to employ it independently. The remembrance of what has already been done, both at home and in this country, will also tend to remove any farther prejudice which may exist against the practical application of the Galvanic Battery.

Having long been impressed with a sense of the great economical importance of the Battery in all the varied operations in which the explosive force of gunpowder is employed, and having had an excellent opportunity of becoming acquainted with its details during the progress of the demolition of the barque "Equitable," in which I had the pleasure of being employed under Capt. Fitzgerald, I was led to prepare this paper, in the hope of rendering the experience then attained, available to the fullest extent for the benefit of others under similar circumstances. After a considerable portion of it had been written, I learned that a pamphlet by Col. Pasley on the same subject was in course of publication, and I therefore immediately laid my paper aside. On receiving Col. Pasley's pamphlet, however, I found it was entirely confined to details of his own plans, and as experience had proved that these admitted of most material improvements and modifications, I conceived my paper might still be useful, and accordingly resumed and completed it. The original plan has been extended by the addition of a section "on the Theory of the Battery," in which the recently published views of Sir Michael Faraday on this long disputed point, have been briefly developed; and as his researches have entirely removed it from the domain of "doubtful knowledge," as he himself terms it, to that of inductive certainty, the addition may prove interesting to those who desire to understand the principles as well as the practical applications of the Galvanic Battery.

SECTION I.—*The Construction of the Galvanic Battery.*

The elementary form of the Galvanic Battery consists simply in the interposition, between two plates of different metals, (usually copper and zinc) of a fluid capable of exerting some action on one of these plates, while it has none, or at least a different one, on the other. A communication established between the plates, either by direct contact, or by the interposition of some conducting substance, then admits of the circulation of a current of Galvanic electricity.

It would be foreign to the design of this paper, to dwell upon the various combinations and modifications of the above elementary Battery, by which different compound circles have been formed; and information concerning these is the less called for, since all have been recently

superseded by an arrangement due to Professor Daniel, in which the removal of the defects of former constructions has been accompanied by some most important and peculiar advantages. Of this alone, therefore, will the details be given, and as zinc is procurable in this country, both in the massive and laminar states, a simple modification of the constant Battery adapted for the use of each, will be described.

In the original form of the constant Battery in which the zinc is [Fig. I. a.] used in solid rods, the copper element consists of a cylinder of that metal in its thinnest obtainable state. The cylinder is formed, as shewn in Fig. I, with a small collar, and to one side of it a small copper cup to contain mercury, or a clamp-screw socket for facilitating metallic connections throughout the Battery, is attached.

The zinc element is a rod of that metal, varying in diameter and [Fig. I. b.] length, according to the strength required for the Battery, perforated at one extremity by a thin piece of wood, which, on the zinc being inserted within the cylinder, rests on the collar, and prevents any direct contact of the two metals. The rod is usually amalgamated with mercury, as will subsequently be described, and its exterior end is made to terminate in a small mercurial connecting cup, or clamp-screw.

The principal objection to the earlier forms of the Battery arose from the rapidity with which the energy of their action was found to decline. On this being traced to the deposition of particles of reduced oxide of zinc on the copper plate, in consequence of certain chemical actions within the cell, its recurrence was prevented in the constant [Fig. I. c.] Battery by the interposition of a membranous partition between the two metals. This membrane is usually made of ox gullets, and is so constructed, as readily to fit on to the collar of the copper cylinder. Thus, then, the Battery when complete, with the exception of the solutions, consists, (1) of the copper cylinder; (2) of the membrane within this; and (3) of the zinc rod separated from the copper by the membrane. The dimensions vary according to the strength required for the Battery; that employed by Col. Pasley in his experiments in February 1839, consisted of 10 cylinders, 21 inches high, by $3\frac{1}{2}$ ditto in diameter, with zinc rods one inch in diameter.

The modification of the constant Battery necessary for the employment of sheet zinc, consists simply in making the copper cells rectangular instead of cylindrical, and the adoption of this form is much

accelerated by employing pasteboard instead of ox gullet partitions, a suggestion due to Dr. O'Shaughnessy of Calcutta. The details are as follow;—

1. The dimensions having been decided upon, a piece of sheet copper of [Fig. II. a.] the proper size, is to be formed into a rectangular cell, the junctions of the side pieces and bottom being soldered with hard brass solder. As the power of a Battery is considerably augmented by bringing the opposite surfaces of copper as near as possible to each other, the edge and bottom pieces of the cell are usually very small in proportion to its sides. When the latter are 14" or 15" square, the former may conveniently be made half an inch in breadth. A small connecting tube, about an inch in depth, or a connecting screw soldered at the top of one of the edge pieces completes the copper element.

2. The partition cases are made of common strong brown pasteboard, [Fig. II. c.] two pieces of this being laid together, and their edges or three sides compressed between strips of teak wood, half an inch in breadth, 1-8th in thickness, the length being regulated by the dimensions of the copper cell into which the case should slide easily. Screw nails of copper, if such are to be obtained, but otherwise of iron, passed through the teak binders and the pasteboards, render the case water-tight at the edges, and complete its manufacture.

The zinc element consists of a piece of the sheet zinc of commerce [Fig. II. b.] (spelter) of such a size, as to admit of its readily passing inside the pasteboard case, and rounded off, as shown in the sketch. A thick copper wire is soldered to it, to facilitate the connections throughout the Battery, by dipping into the mercurial cups above described.

A Battery of this rectangular form was used in the destruction of the barque "Equitable," having side pieces 14" $\times$ 14", edge and bottom ditto 14" $\times$ 1", pasteboard cases 13½" $\times$ 13½", and zinc plates 12" $\times$ 12", the number of cells employed being 12.

SECTION II.—*Of the Exciting Solutions for the Battery—their nature, preparation, and proportions.*

It has been found by experience that strong chemical action on the zinc of a Battery, with the interposition of a good conducting solution between the zinc and the copper, are the conditions by which powerful galvanic action is insured.

With the constant Battery, solutions are always employed in pairs, of which sulphate of copper invariably forms one, and sulphate of soda or dilute sulphuric acid, may be used indiscriminately as the other. A saturated solution of sulphate of copper, or blue stone, is prepared by adding this substance to boiling water till the water ceases to dissolve it, and then allowing the mixture to cool. Should any crystals of the blue stone be deposited during the cooling, it is a satisfactory proof that the solution is fully saturated; if no such deposit takes place it is advisable to add more of the salt to the water. A simple method of ascertaining, during the progress of preparation, whether the solution has reached the point of saturation, is to place a single drop on a piece of glass, and mark if minute crystals, or solid matter, are immediately deposited, if so, the addition of blue stone may be discontinued. The proper strength will readily however be estimated after a little experience from the intensity of the blue colour of the solution. A proportion of one part of blue stone to three parts of water by weight, has been found by experiment to be most effective, and a large copper cooking vessel is perhaps the best utensil for boiling the mixture in. The sulphate of copper is obtained in the bazaar under the name of "Nila tutiya," and at an expense of from five to seven annas per lb.

The solution of sulphuric acid, or vitriol, hitherto employed in the cylindrical Battery, is made by mixing one part of strong acid with eight parts of water.

The solution of sulphate of soda, or Glauber's salts, which has been used with the blue water in all the experiments to be subsequently detailed, is prepared by dissolving one part of the salts in eight or nine parts of warm water, and allowing the mixture to cool before use. Its native name is "Kari nimuk," and it is obtainable to any extent at the trifling expense of two rupees per maund.

It is unnecessary to notice the numerous other kinds of solutions which have been proposed, as the preceding are at once effective, abundant, and simple, and will amply suffice for every practical purpose.

SECTION III.—*Of the Arrangements for bringing the Battery into action, and the precautions to be observed thereupon.*

The first step towards bringing the Battery into action after all the preceding details have been completed, is to charge the cells with

the exciting solutions. The membranous bag of the cylindrical Battery is to be filled with the dilute solution of vitriol, so that this may be in contact with the zinc rod, and the space between the membrane and the copper is to be charged with the saturated solution of blue stone.

In using the rectangular Battery, it is necessary to soak the paste-board cases in the dilute solution of sulphate of soda, till they are thoroughly saturated. Each copper cell is then to be made about two-thirds full of the blue stone water, and subsequently the damped paste-boards are to be respectively inserted. The solution of soda is then to be poured inside the cases till the blue water rises to within an inch of the mouths of the cells, care being taken that no extensive intermixture of the two liquids takes place. In this case sulphate of soda is in contact with the zinc, and sulphate of copper with the copper elements of the battery.

The cells having thus been charged, the small connecting cups are then to be partially filled with mercury, and to complete the circuit throughout the entire battery, the wire attached to zinc No. 1, is made to dip into the cup of copper No. 2; the wire of zinc No. 2 into the cup of copper No. 3; and thus the zincs of the series are to be each connected with the adjoining coppers. By this arrangement, a copper cup is left vacant at one extremity of the battery, and a zinc wire unemployed at the other. These are usually called the poles, and through them the power of the battery is directed as occasion may demand.

When the zinc plates are new, the solutions well made, and the connections perfect, indications of activity may usually be obtained a few minutes after the battery has been charged. The junction of the two poles by means of a short piece of copper wire having one of its extremities terminated by a small portion of very fine platinum or iron wire, will afford immediate proof of the circulation of the galvanic current, by the heating of the small wire to a degree dependent on the intensity of the action. Should it appear that the ignition is not so decided as might be expected from the size of the battery, it is probable some accidental interruption has occurred within the circuit, and the action of part of the cells been thereby neutralized. To ascertain the locality of this interruption, the test-wire is to be retained in contact with one pole, and the platinum at its extremity made to communicate with each

cell in succession, beginning with the most distant. Passing thus along the battery, the total cessation or marked diminution of the heating power at any one point will indicate the accident to have taken place there, and on examination it will usually be found that either the connecting wires have slipped out of the mercury cups, or that their extremities have become corroded, and unfit for insuring perfect metallic contact, or that the connections have been imperfectly made. The removal of the impediments will be indicated by the full development of the power of the battery, in the intense ignition or fusion of the fine test-wire.

When batteries of a considerable number of cells are employed, it increases materially their igniting power to make the cells act in pairs by connecting two zinc plates directly with two copper cells, so that they may act as one, but with double their former surface.

Reference was formerly made to the propriety of occasionally amalgamating the zinc plates and the extremities of the connecting wires. With the former this is effected by washing the surface of the zinc with a weak solution of sulphuric acid, and then applying a little mercury, which immediately combines with the zinc, and renders its surface bright and smooth. Care must however be taken in handling plates after amalgamation, as they become exceedingly brittle. To amalgamate copper wire, the simplest plan is to brighten the surface, and then to rub the brightened portion with a piece of soft leather to which a little mercury has been made to adhere by means of a thin coat of tallow. After continuing the friction for a short time, adhesion of the mercury to the copper is effected.

The mercury employed in these manipulations generally becomes impure, it may however be purified again sufficiently for use, by straining it through a piece of fine cloth of any kind, by which the dust &c. is removed.

When the object for which the battery was put in action has been accomplished, the zinc plates should be immediately withdrawn from the pasteboard cases, and well washed with pure water till all the black deposit which will be found upon them is removed.

Having recently had an opportunity of perusing Sir Michael Faraday's admirable "*Researches in Electricity*," I am indebted to that work for the following remarks relative to some farther precautions to

be observed in the use of the Galvanic Battery :—“ *Weak and exhausted charges*, should never be used at the same time with *strong and fresh ones* in the different cells of a trough, or the different troughs of a battery ; the fluid in all the cells should be of the same strength, else the plates in the weaker cells, in place of assisting, retard the passage of the electricity generated in, and transmitted across the stronger cells.”

“In the same manner, the association of *strong and weak* pairs of plates should be carefully avoided.” “The *reversal*, by accident or otherwise, of the plates in a Battery has an exceedingly injurious effect. It is not merely the counteraction of the current which the reversed plates can produce, but their effect also in retarding, even as indifferent plates, and requiring decomposition on their surface in *accordance* with the course of the current, before the latter can pass, is very deleterious. I find in a series of four pairs of plates of zinc and platina in dilute sulphuric acid, if one pair be reversed, it very nearly neutralizes the power of the whole.” Another very serious impediment to the full action of the battery, is the deposition of copper on the surface of the zinc. This generally arises from the extensive intermixture of the solutions in consequence of imperfections in the partitions. Great attention ought therefore to be paid to keeping these water-tight at their edges, so that intermixture may only take place through the pores of the substance composing them. In my own experience, I have occasionally found the entire igniting power of a large twelve cell battery lost, from the preceding cause, and I find Faraday repeatedly cautions us against it.

SECTION IV.—Of Conductors—their nature, uses, and modes of construction.

When the Galvanic Battery is required to produce its igniting effects at a distance, as is the case in all mining operations, a path must be provided along which the generated current can find a ready and uninterrupted passage. Such a path is best furnished by metallic wires, the conducting power of the metals being very much superior to that of any other class of substances. Of the metals, copper is invariably preferred, in consequence of its high conducting power, its

ductility, flexibility, and cheapness. The dimensions and other details connected with the conductors are determined by the nature of the circumstances under which they are to be employed, which may be classed under three heads :—

I. When the conductors are simply led along the surface of the ground, as in blasting rocks in quarries.

II. When the conductors are led under the surface of the ground, as in military mining.

III. When the conductors are immersed in water, as in sub-aqueous mining operations, for the removal of sunken vessels, or rocks in the beds of navigable rivers, &c.

In the first case, the conductors require no protection whatever, and may be formed of naked wires, care being however taken that while the operations are in progress, no metallic contact takes place between them. This might be effectually guarded against by inserting corks or pieces of wood between the two wires, at convenient intervals, throughout their length.

Our information relative to the best arrangements for conductors employed in military mining operations is still very limited, a few experiments due to Colonel Pasley being all that has yet been published on this branch of the subject. It is only at establishments where military works are continually being executed, that facilities for experiments of this kind can be obtained, and it might be worth while on the part of Government to sanction a series of them, at the headquarters of the Sappers and Miners at Delhi, where, during the practice season, all the requisite facilities would be readily available. Colonel Pasley employed the same conductors in his military mining experiments as in his sub-aqueous explosions; they were elaborately insulated by repeated applications of water-proof composition, tape, and spun yarn, as will be more fully described hereafter. Although I feel considerable hesitation in venturing to express an opinion on a strictly experimental point, I am yet inclined to believe that, especially in dry earth, the minimum of insulation will suffice; a single covering of tarred tape to each wire, would, I believe, prove effectual under such circumstances.

In the third and last case, when conductors are immersed in water, the arrangements for insuring their efficiency are necessarily more

intricate. Water, especially when holding saline matters in solution, being a good conductor, its contact with the wires during the passage of a galvanic current would tend much to diminish the igniting power of this; to prevent such an effect is therefore of primary importance in the formation of conductors for sub-aqueous operations. Colonel Pasley, to whose zeal practical science is so much indebted, has described a very effectual method for insuring the insulation of conducting [Fig. III. a.] wires. In his plan "A $1\frac{1}{2}$ inch new tarred rope of the intended length of the conducting wires is passed slowly through boiling Stockholm tar, which renders it impervious to water,—a necessary process, or the rope on becoming wet after the wires are attached to it, as described below, would shrink one foot in 100 feet, and draw the wires into kinks." Two copper wires *b.* each 20 feet longer than the rope, after being annealed, are separately coated with water-proof composition (made by melting 1 lb. of pitch, 2 oz. of bees' wax, and 2 oz. of tallow together, taking care that it never boils) and are covered with cotton tape, which is bound round the wire while the composition is hot. The wires are then bound to the rope by strong packthread, *c.* a turn being taken round each wire every time to prevent the *d.* possibility of their shifting. This being done, they are to be bound round again with coarse tape $1\frac{1}{4}$ inch wide, after another *e.* coating of composition has been laid on. Lastly, the whole must be served with new tarred yarn, and again paid over with the composition, when the process is complete. These arrangements, there can be no doubt, would be most effective in preventing any water from reaching the wires, but the resulting conductor is objectionable on account of its very great weight, and the difficulty of managing it when its length is considerable, especially in situations where strong tides and currents [Fig. V.] are to be contended against. In a modification of this plan, adopted in some experiments in Fort William, to be subsequently detailed, the preceding objections were, to a considerable extent, *a.* removed. The rope and coatings with tape were entirely dispensed with, the wires were each served with tarred rope yarn, over *b.* which a coat of dammer and grease was laid, the two wires were then lashed together by rope yarn, another coat of composition applied, and the conductor was complete. Five hundred feet of conductor, or one thousand feet of wire were thus prepared, immersed in salt water,

subjected to great strains, and were found most effective. The only objection to the plan arose from the tendency of the thick wire to break, and difficulty of reaching the fracture in consequence of the strong adhesion of the insulating material to the wire. This of course admits of being readily obviated by annealing the wire, or employing a rope of small wires, instead of one thick one.

Another method for making conductors for sub-aqueous explosions [Fig. IV.] characterised by great simplicity, and possessing several important advantages, has been suggested by Dr. O'Shaughnessy. In this *a.* only one wire is insulated, by passing it through a series of corks, which are subsequently coated with water-proof composition, and wrapped round with wax cloth, or some other impervious substance. *b.* The second wire remains unprotected, and is simply tied with twine to the corks. The chief objection to which, in practice, this plan has been found subject, has arisen from the breaking of the corks across, and the consequent exposure of the insulated wire to metallic contact *c.* with the other, or with adjoining substances. This objection might be removed by serving the corks round with yarn, which, without destroying the buoyancy they possess, would effectually remove the danger of accidental contact, or by covering the wire with tape and water-proof composition, prior to its being passed through the corks. In all cases, however, in which charges are employed at great depths, more perfect insulation than this plan affords would, it is conceived, be essential. Under pressure, the corks become saturated with water, and the consequence is that there is then no actual insulation of the wire. To form a perfect conductor, the plan for entire insulation ought therefore to be adapted for that portion of the wires passing vertically downwards, and the corks should be used for the horizontal portion; lightness and buoyancy will thus be combined with complete insulation of that part where insulation is essential, and all risk of failure from accidental metallic contact, or diminution of the heating power of the battery, avoided.

The length of conductors is regulated by the limits of danger from the effects of the explosions, beyond which it is essential to the security of those engaged in the operations, that they should extend. This limit will necessarily vary under varying circumstances, and cannot always be determined with perfect accuracy. In blasting rocks and

military mining, where the charges are carefully calculated to produce certain definite effects, the limit of danger may generally be known, or at least easily determined, but where large sur-charges are employed, experience is still required to shew accurately the extent to which their effects will reach. On this point Capt. Fitzgerald, in his report on the operations for destroying the "Equitable," remarks, "the limit of actual danger with a charge of 2050 lbs. of powder, in a depth of thirty feet of water, may from such experience as this single instance affords, be calculated as something beyond 120 feet. At 200 feet it is conceived that a person in a substantial boat would be perfectly safe, alike from the effects of the waves and the fragments of the wreck ;" but should the charge be fired directly from a boat, he recommends "that for charges of the above description, the main conductors should not be less than 250 feet in length." These remarks must of course be received with the caution required by the limited experience on which they are founded, but they will furnish some standard to which, under similar circumstances, reference can be made. The depth of water most materially influences the limit of danger, which rapidly diminishes as that increases. In Colonel Pasley's operations at Spithead, when the depth was about ninety feet, the limit of danger appears to have been scarcely beyond fifty or sixty feet, although the charges ranged between 2000 and 2500 lbs., and instead of a lofty column of water being thrown up, the elevation of the surface over the charge appears to have been but slight, and the visible disturbance comparatively trifling.

In long conductors, it is impossible to have the wires continuous throughout, and the proper formation of the junctions is of essential consequence to their efficiency. The ends of the wires to be connected should either be strongly brazed together, or if this may be impracticable, they should be twisted together in the smallest possible twists for a length of at least six inches. A few turns, or imperfect contact, should never be considered sufficient, as such connections diminish the igniting power of a battery most seriously, while, on the other hand, well made junctions do not perceptibly affect it. To prove this, a thin wire, 1-20th of an inch in diameter, and 100 feet in length, was taken, and the minimum number of cells required to ignite dry saltpetre cloth ascertained. When the experiments commenced, five junctions existed in the conductor itself, while there were two more at the poles of the

battery, and other two at the extremities to which the platinum igniting wire was attached. With these nine junctions, five cells of a battery 14 by $\frac{1}{2}$ caused saltpetre cloth to ignite, but four cells were not able to effect this. New junctions were made at the termination of each experiment, till from nine they extended to *twenty-four*, and still the same strength of battery sufficed to insure the ignition. The junctions were carefully made, and the contact rendered as perfect as possible.

When the distance from which a charge is to be fired is increased, either the strength of the battery, or the diameter of the wires employed, must be increased also. The exact proportion existing between these increments has not yet been decided, and the results of experience, as far as it has extended, must on this point guide our proceedings. Colonel Pasley states that with a battery of 10 cylinders, 21 inches high and $3\frac{1}{2}$ inches in diameter, having zinc rods 21 inches long and one inch in diameter, he invariably succeeded in igniting charges at 500 feet distance with copper wires 1-5th of an inch in diameter. The following experiments were made in Fort William with a battery of the rectangular form, consisting of 12 cells, each 14 inches square on the sides, having edge and bottom pieces 14" by $\frac{1}{2}$." The zinc plates were new and unamalgamated, the pasteboard cases in good order. The solution of sulphate of copper in the proportion of 1 of salt to 3 of water, the sulphate of soda 1 salt to 8 water. The quantity of the former in each cell was $2\frac{1}{2}$ lbs. by measure, of the latter $\frac{3}{4}$ lb., and the battery was found to be in excellent action a few minutes after the solutions were poured in. The igniting effect was ascertained by bringing a small piece of platinum wire, forming part of the circuit, in contact first with dry cloth saturated with saltpetre, and afterwards with fine dry Dartford powder.

Experiment 1. The length of the circuit in this experiment was 300 feet, each conductor being 105 feet long, and composed of three strands of copper wire, each 1-20th of an inch in thickness, twisted like a rope. With four cells immediate ignition of saltpetre cloth was effected, but with three cells it was not till after some time, that the same effect was produced. With four cells the powder ignited readily, but I found it impossible to effect ignition with only three cells.

Experiment 2. The same conductors reduced to 50 feet.

2 cells produced immediately ignition of the cloth.

1 cell singed the cloth, and made it black, but could not ignite it.

2 cells caused the powder to explode directly.

1 cell caused the powder to smoke, but could not ignite it.

Experiment 3. Conductors of single wires, 1-20th of an inch in diameter and 50 feet in length each, were now employed, and the following results obtained :—

4 cells ignited saltpetre cloth immediately.

3 cells merely singed it.

4 cells ignited powder immediately.

3 cells had no effect whatever.

Experiment 4. The same conductors were employed, but thin brass wire was substituted for platinum.

5 cells caused the ignition of saltpetre cloth.

6 cells ditto of powder.

This experiment involves a question of some importance; viz. the substitution of some other material for platinum, which in this country is most exorbitantly expensive. An interesting series of experiments might be made on this point, by which our resources could not fail to be increased.

With the full power of a 12 cell Battery, I have frequently ignited charges of powder in water, at distances varying from 450 to 500 feet, employing insulated conductors; and by such a Battery was the final destruction of the "Equitable" effected, where the conductors were 150 feet in length, 120 of which were placed horizontally, the remaining 30 vertically in the water.

Before concluding this Section, it may be well to describe some expedients which, under certain circumstances, have been employed for the purpose of diminishing the lengths of conductors. The idea of effecting the completion of the galvanic circuit by means of a self-acting mechanical arrangement, appears to have originated with Mr. Martyn Roberts, who claims to have been one of the first who applied the Battery to useful purposes. With the details of Mr. Roberts' apparatus employed in his blasting experiments in Craig Leith Quarry, I am not sufficiently conversant to be able to describe it, but in blasting, such

an apparatus would seldom, if ever, be necessary. It is in removing obstructions to river navigation, where strong tides and currents are to be contended with, making it essential that the conductors employed should be reduced to their minimum length, that self-acting dischargers may be employed to the greatest advantage. We are indebted to Dr. W. B. O'Shaughnessy for an ingenious plan for such a [Fig. VI.] discharger, of which the following are the details. The discharger consists of two distinct parts, having distinct offices, one being intended for completing the circuit, and effecting the ignition of the powder, the other for breaking the circuit, should any accident delay the explosion, and so rendering it perfectly safe to approach the Battery, and if possible ascertain and remove the cause of failure. These two objects [Fig. VI.] are effected by causing wires to pass, as shewn in diagram No. 6, into four glass tubes partially filled with mercury. Over these, fixed in a small wooden framework, is placed a watch, for the hands of which a thin piece of sheet copper is substituted. This is fixed on the arbor of the hands, and each extremity carries, suspended from a short arm, a copper wire, bent like the letter U. The length of the legs designed for completing the circuit is so regulated, that on the copper hand being set to any specified number of minutes, they will not come in contact with the mercury in the tubes till that time has elapsed. Meanwhile the legs of the other wire have been immersed in the mercury of their tubes, but if the circuit is completed without ignition, then the copper hand continuing to traverse the dial of the watch in four or five minutes more lifts them out, breaks the metallic continuity of the circuit, and thus effectually prevents all risk in approaching the Battery. This form of discharger was successfully employed on the occasion of the first explosion of the "Equitable" in the river Hooghly, but it was then apparent that the utmost delicacy was requisite in making its adjustment. This delicacy and minuteness of detail must always prove serious defects in any form of apparatus employed in practical operations, in which so many risks of derangement are incurred, and in the case of the watch-discharger, the expense is an additional objection. The idea of employing such an apparatus, having however been suggested, there was comparatively little difficulty in designing a form of it which should not be liable to the preceding objections, and one was accordingly contrived, which was successfully employed throughout the remaining operations for destroying the "Equitable." The principle of

this will readily be understood by a reference to Diagram No. 7, by [Fig. VII.] which it will be seen that only two mercurial tubes, with one bent wire, are employed. The wire *c. c.* suspended with its legs dipping a little way into the tubes, is attached by means of a thin metallic chain and hook to a loop of string (saturated either in saltpetre or powder, so as to make it readily combustible) which passes through the composition of a portfire *a.* from which, prior to its being fixed in the wooden stand, part of the paper casing has been removed, as shewn at *h. h.* This portfire burning down, ignites the combustible string, and the bent wire falls by its own weight into the mercury, thus completing the circuit. Should any accident delay the explosion, then another portfire *b.* calculated to burn four or five minutes longer than *a.* discharges a weight *d. d.* attached to it by means of a loop of string, rendered combustible as before. This weight on falling, raises the bent wire to which it is fixed by means of a thin chain, completely out of the tubes, and thus effectually breaks the circuit. On the first occasion on which this portfire stand was employed, it was discovered that the composition of the portfire *a.* just as it burnt out, fell into the tubes and checked the free action of the apparatus, but this was immediately afterwards rectified by the addition of a small copper plate *e.* for the portfire to rest upon, in the centre of which an aperture was pierced, just large enough to admit of the combustible string passing through. Throughout the very extensive series of experiments, which was made to test the action of the apparatus prior to its employment, on the occasion of the final demolition of the "Equitable," no instance occurred in which the composition, even in the smallest quantity, fell into the mercurial tubes, and this result was the more satisfactory, as some considered the above defect fatal to the practical utility of the plan. Its susceptibility of derangement was severely tested on the day of the explosion, as the water was very rough, and the wind high, so that the boat in which the apparatus was fixed, was continually coming in collision with the neighbouring row-boats, and although large quantities of the solutions of the batteries were thrown out in consequence, no part of the portfire stand was in the least degree disturbed, its subsequent action being as complete as could have been wished. The expence of the portfire stand is extremely trifling, as it may be made of any old materials which may be available.

SECTION V.—*Of the Application of the Galvanic Battery in Blasting Rocks.*

The arrangements necessary for the employment of the Battery in blasting operations, are exceedingly simple. The blast hole having been prepared, and the charge introduced, the igniting wires must be inlaid in a conical piece of wood, and fixed in the grooves prepared for them by a thin wedge of wood, as shewn in Diagram No. 8. The [Fig VIII. a.] igniting wires projecting about an inch beyond the base, or larger end of the cone, must be connected by a fine platinum or iron wire, and round this a cartridge of finer priming powder must be placed. The cone is then to be inserted in the blast hole, and by gently pressing it down and turning it round, the larger end should be made to rest on the charge. A tamping of small fragments of rock must then be poured in over the cone, and the whole arrangements are complete. The main conductors should then be attached to the priming wires, and on the circuit being completed at the Battery explosion will ensue. In the event of the common methods of tamping being employed, it would perhaps be the best plan to continue the use of the priming needle, and have an open communication from the surface through the tamping to the charge. The priming wires, inlaid in opposite sides of a bamboo, could then be introduced, and the igniting wire placed in direct contact with the powder of the charge. Had there been satisfactory grounds for believing sand a good tamping material, the use of the battery would have been much facilitated, as it would only have been necessary to pour the sand into the blast hole after the wires had been properly arranged; but I have in another place detailed some experiments, which, as far as they extend, militate against the employment of this material in blasting, and confirm Colonel Pasley's previously expressed unfavourable opinion of it.*

For blasting rocks under water, a very slight modification of the existing plan will admit of the use of the Battery. The tin case in [Fig. IX. a.] which the charge is to be lodged, must be made with a collar about three inches high, and $1\frac{1}{4}$ inch in diameter. A wooden plug *b*, must be turned to fit closely into this collar, and grooves $\frac{1}{4}$

* Professional Papers of the Madras Engineers, Vol. I.

of an inch deep, cut on its opposite sides. These grooves *c.* are then partially filled, either with common sealing wax or dammer, and the priming wires, previously heated, are made to bury themselves in this. The wax being again softened, a strip of wood is to be forced into each groove over the wire, and every aperture through which the water could force its way, is thus closed. The plug having its inlaid wires connected by the igniting wire, and having a small cartridge attached, must then be driven into the collar of the case, and it only remains to connect the priming wires with the main conductors, lower the charge into the blast hole, and complete the circuit. An arrangement like the preceding was employed in an attempt to fire a charge of powder at the bottom of an artesian well in Fort William, and although the pressure of the water was so great that case after case was burst, yet on no occasion could it be discovered that the water had reached the charge through the plug. A coating of sealing wax, and a tin cap, protected the exterior end of the plug, and prevented the water from passing through the pores of the wood, but this was rendered necessary only by the great depth of water, which was nearly 480 feet.

In some operations, as those for deepening the Pambaum Passage, [Fig. X.] common quart bottles have been used to contain the charges, and when the depth is moderate, I have found, by a great many experiments, that if the priming wires in these are carefully passed through good corks, driven home and coated exteriorly with water-proof composition, the Battery seldom fails to insure their explosion.

SECTION VI.—*Of the Application of the Galvanic Battery in Operations for removing Sunken Vessels from the Channels of Rivers, &c. &c.*

The great value of the Galvanic Battery as an addition to the resources of the engineer, has in no instance been so fully demonstrated as in operations for removing the wrecks of vessels from the channels of navigable rivers, &c. Every one who has obtained his experience from actual practice in such operations, will be ready to bear testimony to the uncertainty, the danger, and the expense of the arrangements previously necessary for effecting the ignition of the

sub-aqueous charges. The employment of the Galvanic Battery as the igniting agent, removes, to a great extent, these objections, and although, in sub-aqueous operations it is at present next to impossible to foresee and provide against every source of failure, yet the probabilities are now strongly in favour of success, whereas formerly they inclined in the opposite direction. Every successive series of operations will furnish us with new information, and every failure of which the cause is detected, will point out to us new precautions, so that in time we may expect to see the arrangements for employing the battery so fully matured in all their details, as to illuminate entirely those sources of accident, which in the existing state of our practical acquaintance with the subject, are so apt to escape undetected.

An object of primary importance in all sub-aqueous explosions, is to render the cylinder in which the charge is to be placed, perfectly water-tight; for, as Colonel Pasley remarks, "if there be even so much as a *pin hole* to admit the water, it will inevitably reach the powder. The material of which the cylinder must be made, will be determined by the depth of water over it. For any depth less than 50 feet, experience warrants me in stating, that a cylinder of wood, prepared like a common cask, bound with iron hoops, having staves an inch thick, and carefully coated exteriorly with sheet lead, will be found effective. Such a cask or cylinder, five feet nine inches long, three feet eight inches bulge diameter, and three feet three and a half inches end diameter, was on one occasion of failure during the operations against the "*Equitable*," left at the bottom of the river Hooghly, under a pressure of fifty-one feet of water, for twenty-six hours, and on being raised and immediately opened, it was found that the entire charge of 2050 lbs. of powder it contained, was as dry and serviceable as when it was originally put in, and was in fact the identical powder with which, a fortnight afterwards, the final demolition of the vessel was effected. This may be considered sufficient to shew that within depths of fifty feet, wooden cylinders cased with sheet lead, can with safety be employed. With a depth of ninety feet Colonel Pasley appears to have found it necessary to have recourse to wrought iron cylinders, but the limit at which the employment of wood becomes impracticable, has not yet been ascertained. We must wait the results of other experiments ere any decided opinions can be expressed; but I am inclined to think that

when the depth exceeds sixty-five feet, a wrought iron cylinder will be found necessary.

For the priming apparatus, the following will, I conceive, be found [Fig. XI.] the safest, and most simple plan. The priming wires *a.* must be inlaid in grooves on opposite sides of a circular rod of teak wood, *b.* about 1' 3'' long, in the manner formerly described (when detailing the experiments in Fort William) with sealing wax and wedges, *c.* An iron tube, formed of a part of an old gun-barrel, about 1' long, and having an iron flange 4'' square, carefully soldered upon it *d.* at about three inches from one extremity, must be prepared, and into this the teak rod with its inlaid wires must be carefully driven, till one end is flush with the exterior end of the tube, or that nearest to the flange. Over this must then be laid a thick coating *e.* of melted sealing wax, which both prevents the water forcing its way through the pores of the wood, and also keeps the priming wires at their points of issue from metallic contact with each other. The interior extremities of the priming wires, *f.* must then be connected by the igniting platinum wire, which it has always, as far as my experience goes, been found necessary to solder to the copper with gold solder. A small cartridge of fine dry Dartford or mealed powder, must then be placed in immediate contact with the platinum. The apparatus might now be introduced into the cylinder, and by means of the flange and screws, fixed there; but it is of much importance to have the means of insulating the priming from the main charge, so that in the event of water penetrating to the one, it may not communicate with the other, and it is also very desirable to have the means of inserting and withdrawing the priming apparatus with facility, so as to rectify any accidental derangement which may take place, and these two objects are fully effected by the following plan, *g.* due to Capt. Fitzgerald. A metallic protecting case is provided for the priming apparatus, and made a fixture within the cylinder *h.* At its mouth a fine screw, at least an inch in length, is made, and on the iron tube, immediately beneath the flange, there must be cut a corresponding screw. By these means the priming apparatus can be screwed in, or removed at pleasure. In finally fixing it in the cylinder, washers of leather covered with white lead must be placed beneath its flange, and the small fixing screws must be carefully

brought home. Over all a disc of sheet lead, must be soldered, *k.* and the arrangements of the cylinder, with the exception of the loading, are then complete. The latter is to be effected by setting the cylinder on one end, and pouring in the powder through an aperture, about an inch in diameter, in the other. This aperture must afterwards be filled by a wooden plug, and all the stray grains of powder being carefully removed, a piece of sheet lead must be soldered over it.

It is an object of some importance to those conducting sub-aqueous operations, to be enabled at any time to assure themselves that the interior circuit of the wires is complete, without being obliged to withdraw the priming apparatus itself. Col. Pasley recommends that this should be done by introducing a portion of slightly acidulated water into the circuit, and noting whether decomposition occurs; but this is a most dangerous plan, and ought never to be adopted. The decomposition of a single grain of water, according to Faraday's recent researches, requires a current of electricity sufficiently strong to keep a platinum wire 1-104th of an inch in diameter and eight inches* long, at a dull red heat as long as the decomposition is in progress, the *quantity* of electricity maintained undiminished. The platinum wire we employ is considerably thicker than the preceding, but still the risk of premature explosion by Colonel Pasley's plan is very great. The danger is removed by employing a very weak galvanic circle and a galvanometer, but as the latter can seldom be met with in this country in its perfect form, I may be permitted, before concluding this section, to describe a simple substitute for it, employed during the operations against the "Equitable" [Fig. XII.] safely and successfully. A piece of copper wire about 1-12th of an inch in diameter, and fourteen feet long, was coiled on a rectangular wooden frame-work, *a.* 6'' long, 3'' broad, and 1'' deep, care being taken to preserve the metallic coils throughout from mutual contact, *b.* The magnetic needle of a small theodolite was then mounted on the point of a common needle, fixed in a thin wooden stand. On placing this within the frame-work, with the coils passing above and beneath it, and directing a galvanic current excited by the

* The above length is stated merely to give some definite idea of the danger incurred; but Faraday states that if the wire were a hundred or a thousand inches in length, and the cooling circumstances alike, the same effect would be produced as if it were no more than half an inch.

insertion of a circle, composed of a single piece of copper and zinc, each 2" by 1', into a glass of very slightly acidulated water, through the wire, the needle was immediately affected. Sometimes it merely trembled violently on its pivot; at other times its deflection was considerable, and it never failed to indicate the passing of a current when the circuit was complete. It is only therefore necessary to make the apparatus to be tested a part of the circuit, and if it does not interrupt the circulation of the current, the same appearances will be observed.

The cylinder is lowered to its position near the wreck to be destroyed by means of rope slings and guys. It is usually slung under the bows of a vessel, having davits or fixed pulleys, through which the suspension ropes are led. At the time appointed for lowering the cylinder, this vessel is moored directly over the wreck, the bows being just over the spot destined for the cylinder, and the lowering is effected by gradually allowing the suspenders to glide over the davits till it is felt that the bottom of the river has been reached. A very simple and ingenious plan for insuring the descent of the cylinder in a horizontal position has been suggested by Capt. Bowman, and consists in marking the two suspending ropes at intervals of a foot or eighteen inches apart. By noting these marks, which are alike at corresponding distances in each suspender, the position of the cylinder can immediately be seen, and if one end is lower than the other, the proper correction can be made.

On connecting the main conductors with the priming wires, the greatest possible care must be taken to ensure perfect contact throughout the junctions. Over each junction a piece of wax cloth or canvas should be wrapped, so as to prevent any contact of the conducting wires at those points, and it is sometimes advisable to lash a rough wooden case over the whole of this part of the apparatus.

SECTION VII.—*On the Theory of the Galvanic Battery.*

The first step towards the establishment of Galvanism as a branch of physical science, was made by Galvani, Professor of Anatomy at Bologna, in the year 1790. The accidental observation of certain muscular contractions in the limbs of a frog lying in the immediate vicinity

of an active electrical machine, and the subsequent discovery that the same movements were produced by touching the limbs with two pieces of different metals, led him to announce that he had discovered a new kind of electricity resident in the muscles of animals. This announcement caused great excitement among men of science at the time, and Galvani's experiments were repeated, with various modifications, in all parts of Europe, being viewed with much curiosity, and giving rise to numerous speculations. The convulsions in the limbs of the frog only took place, it was observed, while sparks passed from the machine, and this fact therefore proved no more than that the muscles or nerves, or the two together, formed a very sensitive indicator of electrical action. It is on the subsequent remark, that by the contact of dissimilar metals, the same convulsions were produced, the science of Galvanism is founded.

The theory by which Galvani accounted for the phenomena he had discovered, was that the electricity originating in the brains of animals is distributed to every part of their systems, and resides especially in the muscles. The different parts of each muscular fibril he conceived to be in opposite states of electrical excitement, and the contractions to be produced whenever the electric equilibrium was restored. This during life was effected through the medium of the nerves, and after death by the intervention of metallic conductors. To the metals themselves he traced none of the peculiar effects produced, considering them quite passive, and only necessary as furnishing channels of conduction for the animal electricity.

These opinions of Galvani were very decidedly opposed, and foremost among his opponents stood Alex. Volta, Professor of Natural Philosophy at Pavia. By him it was maintained that the electricity was developed entirely by the contact of the two metals, and that the muscular convulsions were merely the effects of the passage of the electricity, thus developed, through the nerves and muscles of the animal. The views of Volta were far clearer and more distinct than those of Galvani, and to him belongs the true credit of having called into being the science, which in compliment to him, has been called Voltaic electricity as well as Galvanism. The latter is perhaps the more common of the two, and I have therefore retained it in this paper, but it must be remarked, that the term Galvanic Battery

involves an anachronism, since this instrument was invented some time after the promulgation of Galvani's experiments, and no portion whatever of the credit due to its invention can be claimed for him, it being the result of original and independent investigations by his opponent Volta. In explaining the action of the Battery, Volta assumed that during the whole time the two dissimilar metals were in contact, a certain force was in constant operation, tending to effect the transfer of electricity from the one metal to the other. To this he gave the name of *electro-motive force*. Thus when zinc, and copper are in contact the alleged operation of this force is to impel the electricity from the copper to the zinc, so as to maintain the latter in a positive state relative to the former, which is itself in this case negative. If therefore the redundant electricity of the zinc be by any means carried off, and the deficiency of the electricity of the copper be supplied from other sources, the electro-motive force will immediately renew this difference of condition, and thus maintain a continual current of electric power, flowing always in the same direction. The office of the fluid in a Battery, according to Volta's theory, is simply to conduct the electricity from one metal to the other, and its conducting power determines the effective quantity of electricity which actually circulates in the Battery. The force ultimately generated was conceived to be the sum of all the forces acting in each cell separately, since the impulses given by the electro-motive force to the circulating electricity, were all in the same direction, and each added its effect to that of the preceding ones. Hence then the interposition of any substance between the two poles of a Battery subjected it to the influence of this powerful electric current. The chemical action of the fluid on either of the metal plates was considered by Volta as in no way connected with the origin of the electricity developed, and his theory consequently took no cognizance whatever of its existence. It was soon however observed, that in thus neglecting chemical action, Volta had committed an important, indeed a fundamental error, since it was found that the quantity of Galvanic effect was always in proportion to the energy of the chemical action, and that the extent of surface of contact between the metals, had no relation to the quantity of electricity developed. It was farther found, that metals did not invariably stand in the same electrical relation to each other, but that this rela-

tion was determined by the chemical properties of the fluid, with which they were placed in contact. Facts like these were quite irreconcilable with Volta's hypothesis, and pointed clearly to the very important relation which obtained between the chemical action of the fluid on the immersed metals, and the development of the Galvanic energy. Dr. Wollaston, by whom chiefly Volta's theory was shewn to be untenable, conceived that the current of electricity was originally determined by the oxidation of the zinc, that the fluid of the circle served both to oxidise the zinc and to conduct the electricity which was excited, and that the contact between the plates served only to conduct electricity, and thereby complete the circuit. Succeeding philosophers, did not receive Dr. Wollaston's views as thus stated, and Sir Humphry Davy proposed another theory intermediate between that of Volta and the preceding. He adduced many experiments in support of Volta's statement, that the electric equilibrium, is disturbed by the contact of different substances, without any chemical action taking place between them. He acknowledged however with Wollaston, that the chemical changes contribute to the general result, and he maintained that though not the primary movers of the electric current, they are essential to the continued and energetic action of every Voltaic circle. The electric excitement was *begun*, he thought, by metallic contact, and *maintained* by chemical action.

Such was the state of the question, when, in 1834, Sir Michael Faraday undertook the investigation of the source of the electricity in the Voltaic or Galvanic Battery. The contradictory evidence, the equilibrium of opinion, and the variation and combination of theory, which he found to characterise the labours of all preceding writers on this subject, forced him to repeat and examine the facts stated, and use his own judgment upon them in preference to receiving that of others. His previous discoveries of the identity of electricity and chemical affinity, of the power derived from the action of the Battery, with the power to be overcome in any body subjected to its influence, gave him the means of examining the question with advantages not before possessed by any, and of which he has made such admirable use, that doubt can no longer be said to obscure the subject.

Faraday had always coincided in opinion with those who maintained, that *action* of the Battery was *continued* by chemical action, and that

the *supply* constituting the current was almost entirely derived from that source, but whether metallic contact or chemical action *originated* and determined the current, was by no means clear to him. To set this point at rest, was therefore the first step in his investigations, and seeing no reason if metallic contact was not *essential*, why true decomposition by an electric current should not be produced without it, even in a simple circuit composed of two pieces of metal and an interposed fluid, he accordingly instituted some beautiful experiments under this impression, and persevering, ultimately succeeded in obtaining the most satisfactory evidence that *metallic contact was not necessary to the production of the Galvanic current*. This was farther aptly proved by referring to the spark which appears when the wires of a pair of plates in vigorous action are brought in contact with each other. This spark is occasioned by the electricity passing through a thin stratum of air, and its production proves that electro-motion really occurred while the wires were separated, and anterior to any actual contact between them being the result of the action of pure, unmixed chemical forces.

From his experiments, Faraday accordingly felt warranted in concluding that the electricity of the Voltaic pile is not dependant, either in its origin or its continuance, upon the contact of the dissimilar metals with each other; that it is entirely due to chemical action, is proportionate in its *intensity* to the intensity of the affinities concerned in its production, and in its *quantity* to the quantity of matter which has been chemically active during its evolution. Thus when zinc, copper, and dilute sulphuric acid are used, it is the union of the zinc with the oxygen of the water which determines the current, and though the acid is essential to the removal of the oxide so formed, in order that another portion of zinc may act on another portion of water, it does not, by combination with that oxide, produce any sensible portion of the current of electricity which circulates: for the quantity of electricity is dependent on the quantity of zinc oxidised, and in definite proportion to it: its intensity is in proportion to the intensity of the chemical affinity of the zinc for the oxygen under the circumstances, and is scarcely, if at all, affected by the use either of strong or weak acid. But in considering this oxidation or other direct action upon the *metal* itself, as the cause and source of the electric current, it is of the utmost

importance to observe, that the oxygen or other body must be in a state of *combination*, and not only so, but combined in such proportions as will constitute a substance capable of decomposition, since without decomposition the transmission of a current cannot take place. The presence of such a substance is therefore essential to the action of a Voltaic circuit, and so intimate is the connection between its decomposition and power of transmitting a current, that if the one be checked, the other is checked also, and if the one be stopped entirely, the other stops with it. No Voltaic Battery has been constructed in which the chemical action is that only of combination; *decomposition is always included*, and is, according to Faraday's belief, an essential chemical part.

But as the quantity of electricity set in motion by the decomposition of a certain quantity of anelectrolytes or decomposable substance, is definite in its action, and cannot by any means be increased beyond a fixed limit, it is evident that the action of each cell of a Battery is not to increase the *quantity*, but the *intensity* of the current circulating. A single pair of zinc and platinum plates throws as much electricity into the form of a current by the oxidation of 32·5 grains of zinc, as would be circulated by the same alteration of a thousand times that quantity, or nearly 5lbs. of metal oxidised at the surfaces of the zinc plates of a 1000 pairs, placed in regular Battery order, because at *each* cell, the quantity of electricity is expended in producing the decomposition of its equivalent of the exciting electrolyte, without which decomposition, as was before remarked, the current could not circulate at all. Hence then the action of each cell is to impel forward the quantity of electricity due to the oxidation of the zinc in any one cell, and thereby to exalt that peculiar property of the current, which we designate intensity, without increasing the quantity beyond that due to the zinc oxidised in that one cell. The waste of power in our common Batteries, in which the zinc of commerce is used, is so enormous as to be almost incredible. Faraday asserts that the chemical action of a grain of water upon four grains of zinc can evolve electricity equal in quantity to that of a powerful thunder-storm, and that with zinc and platinum wires one-eighteenth of an inch in diameter, and about half an inch long, dipped in dilute sulphuric acid, so weak as not to be sensibly sour to the tongue, more electricity will be evolved in

one-twentieth of a minute, than any man would willingly allow to pass through his body at once. The loss with ordinary zinc appears to arise from portions of copper, lead, cadmium, and other metals being set free on its surface by the action of the dilute acid, and these being in contact with the zinc, form small, but very active Voltaic circles, which cause great destruction of the zinc, and in the same proportion as they serve to discharge or convey the electricity back to the zinc, do they diminish its power of producing an electric current, which shall extend to a greater distance across the acid, and be discharged only through the copper or platinum plate which is associated with it, for the purpose of forming a Voltaic apparatus.

These evils are remedied entirely by adopting that process of amalgamation of the zinc described in a former section of this paper, by which its surface is brought into one uniform condition, and those differences of character between one spot and another, which are essential to the formation of the minute Voltaic circles, above alluded to, effectually prevented. Hence the full equivalent of electricity is obtained for the zinc oxidised, and a Battery so constructed is only active while the poles, or, as Faraday calls them, the electrodes, are in connection, ceasing to act, or be acted on, the moment this connection is broken. The superiority of the amalgamated zinc is farther due to the state of the solution in contact with it, for as the unprepared zinc acts directly and alone upon the fluid, which the amalgamated does not, the former by the oxide it produces quickly neutralises the acid in contact with its surface, so that the progress of oxidation is retarded, whilst at the surface of the amalgamated zinc, any oxide formed is rapidly removed by the free acid present, and the clean metallic surface is always ready to act with full energy on the water.

When an amalgamated zinc plate is immersed in dilute sulphuric acid, the force of chemical affinity exerted between the metal and the fluid, is not sufficiently powerful to cause sensible action at the surfaces of contact, and occasion the decomposition of water by the oxidation of the metal, but it is sufficiently powerful to produce such a condition of the electricity (or the power upon which chemical affinity depends,) as would produce a current, if there were a path open for it. Now the presence of a piece of copper touching both the zinc and the fluid opens such a path, and its direct communication with the zinc is far

more effectual than any connection formed between that metal and it by means of any decomposable bodies or electrolytes, because when they are used, the chemical affinities between them and the zinc produce a contrary and opposing effect to that which is influential in the dilute acid; or if that opposing action be but small, still the affinity of their component parts for each other has to be overcome, for they cannot conduct without suffering decomposition, and this decomposition is found *experimentally* to re-act upon the forces which in the acid tend to produce the current, and in some cases entirely to neutralise them. Where direct contact of the copper and zinc takes place, these obstructing forces are not brought into action, and therefore the production and circulation of the electric current are highly favoured. Hence the cause of the very great importance of *metallic contact* in the Voltaic Battery.

The liquid in the cells of the Battery has the power of retarding the circulation of the electricity generated, and it acts injuriously in greater or less proportion, according to the quantity of it between the zinc and copper plates, or, in other words, according to the distances between their surfaces. Hence then the reason of the great increase of power obtained by approximating the two metals, and Faraday states that not only is this power greater on the instant, but also that the sum of the transferable power in relation to the whole sum of the chemical action at the plates is much increased. *Double coppers* owe their advantages in part to the same cause, but derive their superiority chiefly from the circumstance that they virtually double the acting surface of the zinc, or nearly so, the action on both sides of the metal being converted into transferable force, and the power of the Battery, as to the *quantity* of electricity evolved, highly exalted in consequence.

The cause of the heat excited during the passage of a Voltaic current, remains still enveloped in considerable obscurity, and a more intimate acquaintance with the modes of action of electrical forces will be required, ere the difficulty can be fully removed. Uncertain as we still are of the precise nature of the electric current, the conclusion that the ultimate atoms of matter are in some way endowed or associated with electrical powers, is forced upon us by nearly all the great facts of the science. The researches of Faraday have led him to notice the truly enormous quantity of this electrical power, associated with

these particles, and he has found, on evidence to which it is difficult to refuse our assent, that no less than 800,000 charges of a Leyden Battery consisting of fifteen large jars, charged by thirty turns of a powerful Plate Electrical Machine in excellent order, are required to produce electricity sufficient to decompose one single grain of water into its elementary constituents! That the heat developed by the action of a Battery, is due to the mutual electrical action of the particles of matter thus highly charged, was originally suggested by Berzelius, the celebrated Swedish chemist, and of this idea Faraday, in the seventh series of his researches, speaks with great commendation, but in the succeeding series, he finds reason to modify his praise, and states that the heat or light exhibit but a small portion of the electric power which acts, and "are merely incidental results, incomparably small in relation to the forces concerned, and supplying no information of the way in which the particles are active on each other, or in which their forces are finally arranged.

Such being therefore the state of doubt in which the immediate cause of the development of heat by the Voltaic current is involved, I do not dwell longer upon the point; but I cannot close this section without briefly adverting to the very beautiful and comprehensive theory proposed by Faraday to explain the varied phenomena of conduction and discharge, as well as many others to which, as being unconnected with the subject of this paper, I do not allude.

The division of bodies into conductors and non-conductors, or insulators, is nearly contemporaneous with the origin of the science of electricity itself, and the states of conduction and insulation have in all electrical theories been assumed as essentially different, although no one has ever shewn in what their difference consists. By a series of most beautiful experiments, Faraday has however shewn indisputably that they are only extreme degrees of *one common condition*, and that they consist in an action of the contiguous particles of matter dependent on the forces developed by electrical excitements. The first effect of an excited body on other matter in its vicinity is, according to Faraday's theory, the production among the particles of that matter of a peculiar state of polarization, which constitutes *induction*. If this inductive or polarised state continues undiminished, then perfect *insulation* is the consequence. If, on the contrary, contiguous parti-

cles of the matter, whatever it may, be metallic or non-metallic, have the power to communicate their forces, then *conduction* occurs, and is a distinct act of discharge between these contiguous particles. The lower the state of tension at which this discharge takes place, the higher is the conducting power of the matter. Hence then throughout a wire conveying a charge of electricity, there is a constant series of discharges taking place between the contiguous particles of which it is composed ; and Faraday intimates, in the form of a query, the possibility that these discharges may be similar in kind, though almost infinitely different in degree, to those which take place between two charged bodies through the medium of the air, or other insulating substance. A wire, it has been experimentally proved, has the power of sensibly retarding the passage of a current, and this power of retardation may be traced through a chain of substances till it reaches its maximum in air, but nothing can be detected during this process to shew that its nature has in any way been changed or modified otherwise than in degree, and therefore Faraday asks, “ may not the retardation and ignition of a wire be effects exactly correspondent in their nature to the retention of charge and spark in air ? ”

To enter farther upon the various theoretical questions naturally brought before our view in examining the principles of the Galvanic Battery, would extend this paper to a great, and indeed unnecessary, length, and I trust that what has already been said, will suffice to point out the great principles of its action. The chemical theory of the Battery, and indeed the entire identity of chemical and electrical forces, may now be considered as indisputably established by the researches of Sir Michael Faraday, and the question, as was previously remarked, thereby removed for ever from “ the domain of *doubtful knowledge* to that of *inductive certainty*.”

APPENDIX.

Experimental Desiderata.

As many of the details connected with the practical application of the Galvanic Battery still require to be experimentally determined or confirmed, I have thought it might prove useful to append to this paper a few Tabular Forms, shewing to a certain extent the experiments required. Having no higher object than the establishment of rules for guidance in common practice, these forms have not been prepared with a view to great minuteness of quantitative measurement, but they are still, it is conceived, sufficiently extensive to admit of the deduction of valuable practical inferences, and should they not be considered so, they can readily be modified.

In recording experiments, all particulars connected with the Battery employed should be minutely and carefully specified, and it should never be forgotten, that if these are neglected or imperfectly stated, the value of the result obtained is most seriously diminished, and in some cases entirely destroyed. Each series of experiments should be prefaced by a detail of the dimensions of the copper and zinc elements of the Battery; of the state of the zinc rods or plates; of the number of times they may have previously been used; of the state of their surfaces; whether amalgamated or not; of the nature and quantities of the solutions employed; of the nature and state of the partitions of the connections throughout the Battery, and of such other points as the experimenter may consider it useful to note. The same careful detail should be entered into, relative to the conductors used. The results of the experiments should, whenever it is practicable, be entered in their proper columns in the forms immediately on being obtained, as it is impossible to trust to memory for a series of numerical statements, and a single error may cast doubt on a whole set of experiments.

Illustrative Diagrams.

Fig. I

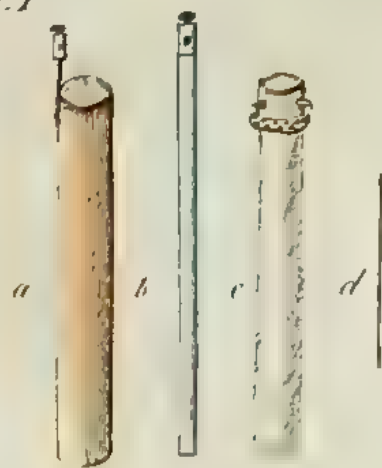


Fig. II

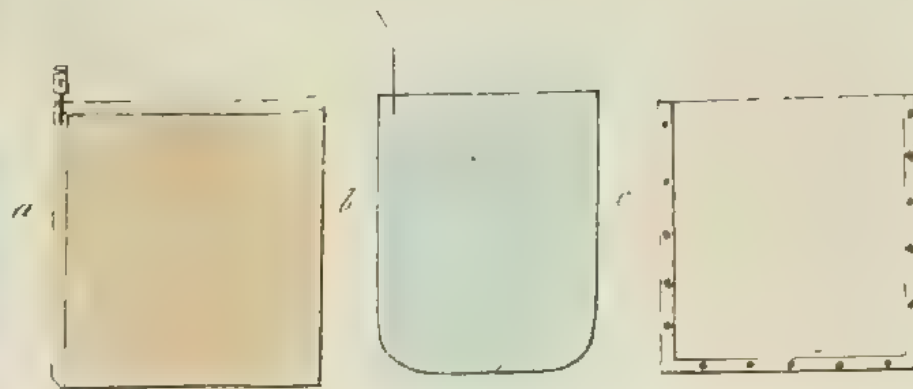


Fig. III



Fig. IV

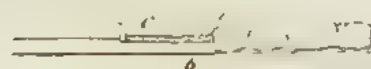


Fig. V



Fig. VI

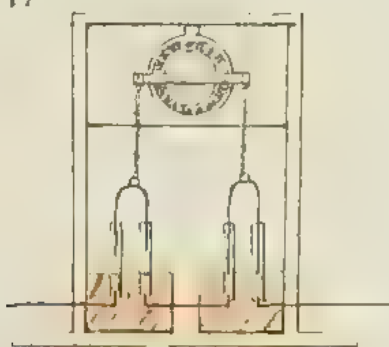


Fig. VII

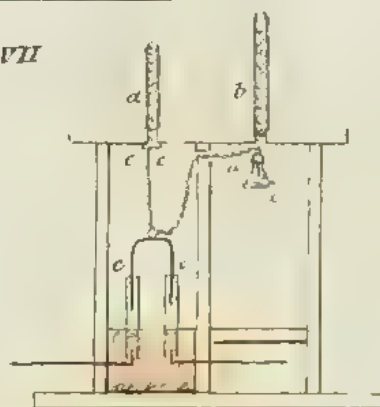


Fig. VIII



Fig. IX

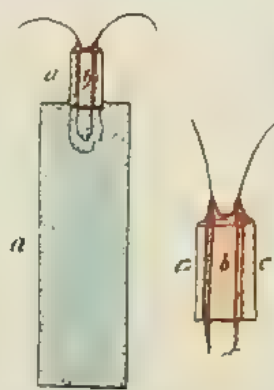


Fig. X



Fig. XI

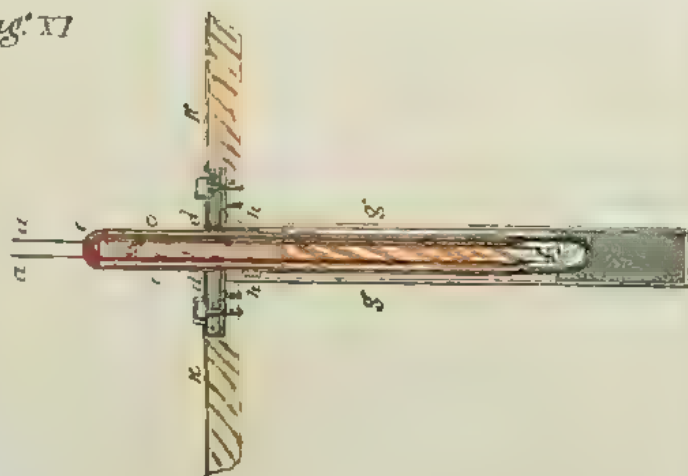
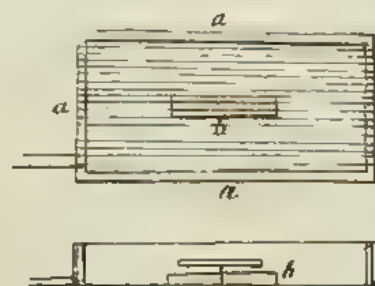


Fig. XII



TABLES OF EXPERIMENTS.

To determine the number of cells of a Galvanic Battery (Dimensions, &c., previously specified) required for effecting the Ignition of different substances, at different distances, and with different Igniting Wires.

FIRST SERIES.

Conductors dry and uninsulated.

No. of Experiments.	Length of Conductor.		Diameter of Conductor.	No. of Junctions in Conductors.	Platinum Igniting Wire, $1\frac{1}{2}$ in.			Iron Igniting Wire, $1\frac{1}{2}$ in.			Brass Igniting Wire, $1\frac{1}{2}$ in.			REMARKS.
					No. of Cells to Ignite. S. P. C.	Ditto, F. P.	Ditto, C. P.	Ditto, S. P. C.	Ditto, F. P.	Ditto, C. P.	Ditto, S. P. C.	Ditto, F. P.	Ditto, C. P.	
1	40	1-6th	8	2	2	3	3	3	4	5	6	7	8	
2	60	0	0	0	0	0	0	0	0	0	0	0	0	
3	80	0	0	0	0	0	0	0	0	0	0	0	0	
4	100	0	0	0	0	0	0	0	0	0	0	0	0	
5	120	0	0	0	0	0	0	0	0	0	0	0	0	
6	140	0	0	0	0	0	0	0	0	0	0	0	0	
7	160	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	
24	500	0	0	0	0	0	0	0	0	0	0	0	0	

* S. P. C., Saltpetre Cloth,
F. P., Fine Powder,
C. P., Coarse Powder,

Conductors increase in length in arithmetical progression, the common difference being 20.

SECOND SERIES.

Conductors in water and uninsulated.

A. Water Fresh.

No. of Experiments.	Length of Conductor.		Diam. of Conductor.	No. of Junctions in Conductor.	Depth of Water.	Platinum Igniting Wire.			Iron Igniting Wire.			Brass Igniting Wire.			REMARKS.
						S. P. C.	F. P.	C. P.	S. P. C.	F. P.	C. P.	S. P. C.	F. P.	C. P.	
1	40	1-6th	8	5	3	3	4	4	4	5	6	6	7	8	
2	60	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	80	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	100	0	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	500	0	0	0	0	0	0	0	0	0	0	0	0	0	

B. Water Salt.

Form similar to the preceding.

THIRD SERIES.

*Conductors in water, but insulated.***A.** *By Colonel Pasley's method.*

Form similar to the preceding.

B. *By Lieut. R. B. Smith's modification of ditto.*

Form similar to the preceding.

C. *By Dr. W. B. O'Shaughnessy's method.*

Form similar to the preceding.

FOURTH SERIES.

*Conductors under ground and uninsulated,***A.** *In Dry Soil.*

No. of Experiments.	Length of Conductor.	Diam. of Conductor.	No. of Junctions in Conductors.	Depth of Soil over Conductor.	Platinum Igniting Wire.			Iron Igniting Wire.			Brass Igniting Wire.			REMARKS.
					S. P. C.	F. P.	C. P.	S. P. C.	F. P.	C. P.	S. P. C.	F. P.	C. P.	
1	40	1-6th	8	4	2	2	3	3	3	4	4	5	6	
2	60	0	0	0	0	0	0	0	0	0	0	0	0	
3	80	0	0	0	0	0	0	0	0	0	0	0	0	
4	100	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	
"	&c.	0	0	0	0	0	0	0	0	0	0	0	0	
24	500	0	0	0	0	0	0	0	0	0	0	0	0	

B. *In Wet Soil.*

Form similar to the preceding.

C. *In Rocky Soil.*

Form similar to the preceding.—Nature, and if possible, the ingredients of the rock to be specified.

FIFTH SERIES.

Conductors underground, but insulated.

Form similar to the preceding.—Nature and extent of insulation to be detailed.